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(UNCLASSIFIED TITLE)  
**EVALUATION OF A HIGH ENERGY  
MONOPROPELLANT**

**Quarterly Report**

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Seattle, Washington

September, 1966

Air Force Rocket Propulsion Laboratory  
Research and Technology Division  
Air Force Systems Command  
Edwards, California

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(Unclassified Title)

**EVALUATION OF A HIGH ENERGY MONOPROPELLANT**

D. C. Maybee

G. F. Dierks

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**QUARTERLY PROGRESS REPORT**

September 1966

Air Force Rocket Propulsion Laboratory  
Research and Technology Division  
Air Force Systems Command  
Edwards, California

Prepared Under Air Force Contract Number AF 04(611)-11549

By

Rocket Research Corporation  
Seattle, Washington

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## FOREWORD

The research program reported here was performed under Air Force Contract Number AF 04(671)-11549 b, Rocket Research Corporation, 520 South Portland Street, Seattle, Washington. The secondary report number assigned by the Contractor is 66-R-73(C).

Captain Joel A. Tolson, USAF/RPC is the Air Force project officer for this program.

The research reported here covers the period June 9 through September 8, 1966.

Mr. Peter Brysse, Director of the University of Washington Environmental Research Laboratories and a member of the Seattle Air Pollution Board, serves as a consultant to the program with respect to beryllium safety aspects. Physical examinations of personnel working on the program are performed by Dr. I. Sealey of the Northwest Industrial Medical Clinic in Seattle, Washington.

This report contains classified information extracted from other classified documents.

Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

William Ebelke (RPC)

Colonel, USAF  
Chief, Propellant Division

**CONFIDENTIAL****ABSTRACT**

(C) This report summarizes the work performed during the second quarter of a 12-month program designed to evaluate and characterize the combustion efficiency of MONEX DW, a beryllium containing monopropellant, in a liquid injection type engine at a nominal 250 lbf thrust level. Initial checkout tests and a series of baseline performance tests have been completed with MONEX A, an aluminum-containing monopropellant. The results of these tests indicate performance of MONEX A increases with increasing chamber pressure. Delivered specific impulse values exceeding 202 lbf-sec/lbm (82% of the theoretical shifting equilibrium value) were measured at chamber pressures greater than 1200 psia.

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**CONFIDENTIAL**SECTION I  
INTRODUCTION

(C) The objective of this program is to evaluate and characterize the combustion efficiency of MONEX DW monopropellant in a liquid injection type engine at a nominal 250 lbf thrust level. This report summarizes the work performed during the second quarter of the 12-month program.

(C) MONEX DW is a high energy heterogeneous monopropellant containing beryllium metal, hydrazine nitrate, hydrazine, and water as its prime components. It possesses a theoretical specific impulse of 302.1 lbf-sec/lbm at 1,000 psia chamber pressure exhausted to 14.7 psia and a density of 0.048 lbs/in<sup>3</sup>.

(C) Preliminary characterization of MONEX DW was initiated under Contract AF-04(611)-9713 (Reference 1). MONEX DW was shown to possess excellent safety characteristics and physiochemical properties comparable to those of hydrazine gel systems for bipropellant application currently under development (e.g., alumizine, and beryllizine (Reference 2)). Preliminary ignition and combustion tests were performed in end-burning motors of up to 100 lbf thrust. These combustion tests indicated that while high conversion of beryllium metal to combustion products can be achieved, poor expulsion of solid combustion products from the chamber occurs under these conditions. The burning of MONEX DW propellants in this manner (small end-burning motors) appears to be invariably accompanied by extensive agglomeration resulting in a large quantity of slag residue remaining in the motor chamber.

(C) The goal of the present program is to extend this work into the area of liquid injection type engines to determine the potential usefulness of MONEX DW as a rocket propellant. While the purpose of the program is the investigation of MONEX DW, the majority of effort to date has been in the area of control test firings of MONEX A. MONEX A, an aluminized monopropellant was chosen for the initial test firings to provide a safe (nontoxic) means of establishing metallized monopropellant ignition and operational procedures and to provide a performance baseline for future MONEX DW testing.

(U) During this report period, the MONEX A checkout test series, and the MONEX A performance baseline tests were completed. These tests complete the planned effort with MONEX A. During these tests, performance was found to increase significantly

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with increased chamber pressure. Specific impulse increased from 67.0% to 82.7% of theoretical shifting equilibrium with an increase in chamber pressure from 355 psia to 1,220 psia.

**CONFIDENTIAL**SECTION II  
TECHNICAL DISCUSSION2.1 General

(U) The objective of this program is the evaluation of MONEX DW in a nominal 250 lbf thrust liquid injection engine. The major effort during the first six months, however, has been concerned with checkout tests and baseline performance tests of the engine system with MONEX A monopropellant. In addition to providing future MONEX DW tests with a baseline for performance, the techniques of ignition and monopropellant engine operation are directly applicable to firings of MONEX DW in the same engines and test system.

2.2 Propellant Preparation2.2.1 MONEX A

(U) To date, 180 pounds of MONEX A G.3-3M1 have been prepared in 4 to 8 pound batches using the previously described method (Reference 3). The propellant has been consumed in a total of 30 checkout and baseline firings.

2.2.2 MONEX DW

(C) Construction, setup, and checkout of a mixer for the preparation of gelled monopropellants has been completed. The mixer (Figure 1) consists of a stainless steel, water-jacketed 2 gallon bowl sealed to an explosion proof, variable speed "Lightnin" motor and shaft by an 8 bolt flange and a vacuum-type, packing gland. Fluid propellant can be bottom cast through a remotely operated, air actuated ball valve. Two 1-inch diameter tubes extending through the water jacket provide a simple method for adding metal powders and liquids. Prior to preparation of MONEX DW, the mixer was passified at 100 to 150°F with a water-hydrazine solution.

2.3 Propellant Analysis2.3.1 MONEX A

(U) A preliminary procedure for determining the chemical composition of MONEX A propellant was completed. This analysis included the determination of aluminum metal, water, M-1 additive, and total nitrogen. No attempt was made

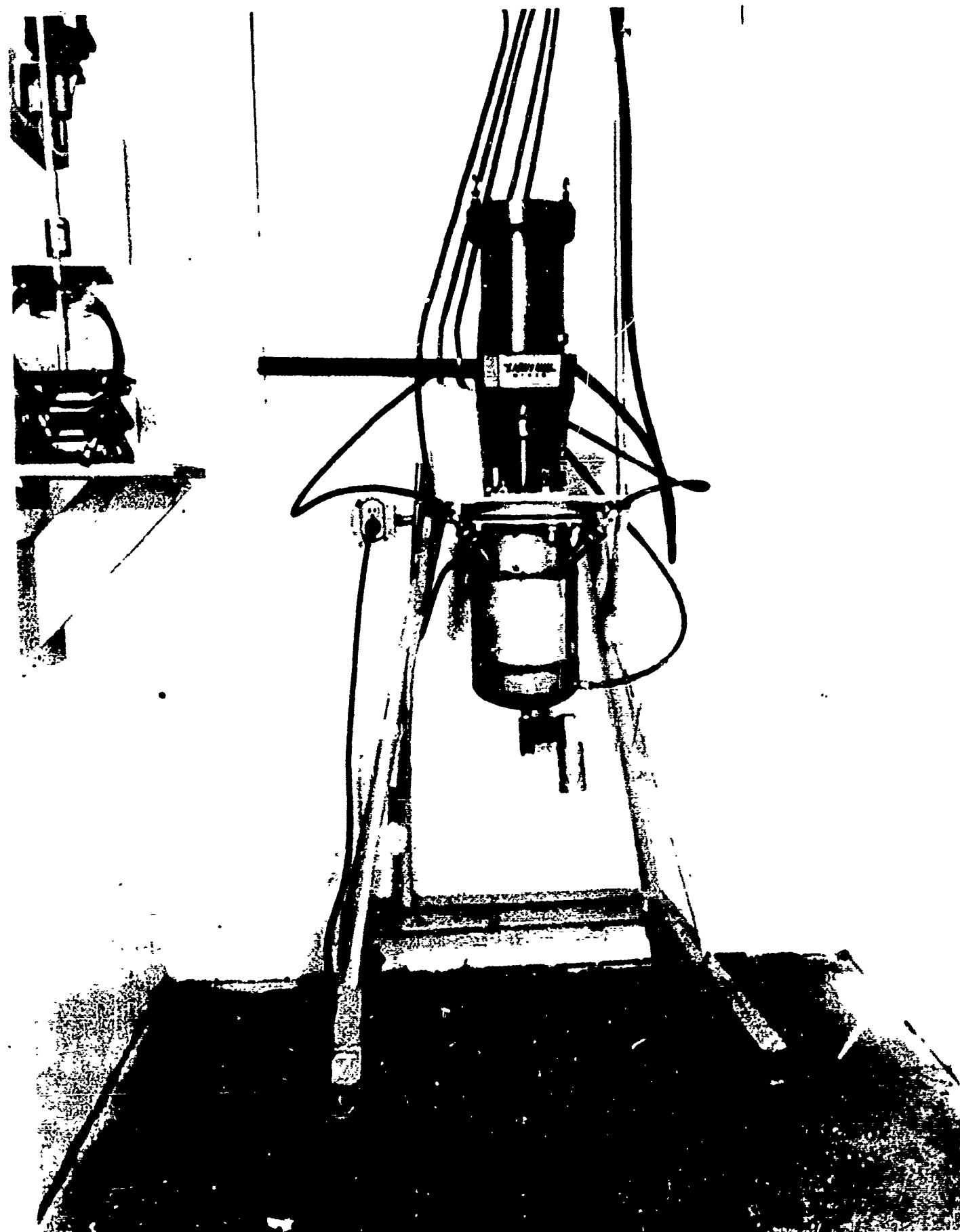


FIGURE 1 PROPELLANT MIXING EQUIPMENT

to determine the concentration of gellant. Analytical results obtained for three batches of MONEX A G.3-3-M1 are reported in Table I.

(U) Aluminum metal is determined by chelometry (Reference 4). The metal present in a propellant sample is dissolved in concentrated hydrochloric acid and complexed with ethylenediaminetetraacetic acid, disodium salt (EDTA). Excess EDTA is back-titrated with standardized ferric ammonium sulfate solution. High purity aluminum wire is used to standardize the method.

(U) Water content is determined by the Karl Fischer method (Reference 5) using an automatic dead-stop titrator. Due to the large quantity of water present in MONEX A, small samples and rapid direct titration with Karl Fischer reagent were necessary to obtain reproducible results.

(U) The M-1 additive is determined gravimetrically by quantitative filtration of the insoluble material obtained from an acid digestion of the propellant sample. No attempt is made to correct for the presence of metal oxide, which, being insoluble in acid, would be removed during filtration. Although not proven, it is suspected that because the gellant is a polysaccharide, it hydrolyzes and becomes soluble during the acid digestion.

(U) Total nitrogen is determined by the Dumas method using an automatic nitrometer. The results obtained from the first two analyses (Batch Nos. 6266-1; 72566-1,2) were consistent (Table I). After additional determinations, however, low values were obtained. Similar data was obtained from standard analyses of acetanilide. It is suspected that this phenomena is the result of instrument malfunction due to contamination from the M-1 additive. Additional tests are to be performed in order to develop an improved analytical procedure.

(U) Bulk densities were determined for all individual batches of MONEX A immediately prior to loading of the propellant feed tank (Table II). Bulk densities were determined by weighing (100 to 200 gm) a known volume of propellant in a graduated cylinder at ambient temperature. True densities were determined by a pycnometric technique using a 50 ml volumetric flask with toluene as the standard displacement liquid.

TABLE I  
(U) CHEMICAL ANALYSES OF MONEX A G.3-3-MI

Batch No.	Density						Composition, weight percent					
	Bulk gm/ml	True gm/ml (77°F)	Aluminum	Water	Nitrogen	M-1	Av.	Repl.	Av.	Repl.	Av.	Repl.
(theoretical)	(1.583)	(35.9)	(26.9)	(11.3)	(5.0)							
62266-1												
72566-1, 2	1.55 (70°F)	1.557	35.2	35.5	27.1	27.1	11.67	11.92	4.96	4.97		
		1.543	34.9		27.0			11.42			4.94	
8366-1, 2	1.53 (70°F)	1.565	35.8	35.7	26.3	26.4	8.92	8.84	4.90	4.91		
		1.561	35.8		26.2			9.00			4.88	
8866-1	1.53 (77°F)	1.578	35.7	35.7	26.8	26.1	10.32	10.62	4.95	4.92		
		1.578	35.6		27.5			10.49			4.97	
81566-1	1.53 (70°F)						10.33	10.65				
									10.33	10.33		
										10.00		

TABLE II  
(U) PROPELLANT BULK DENSITIES  
MONEX AG.3-3-MI

<u>Motor Test No.</u>	<u>Propellant Batch No.</u>	<u>Bulk Density (gm/mil)</u>
B-1, B-2	72566-1, 2	1.55 (70°F)
B-3, B-4	8366-1, 2	1.53 (70°F)
B-5, B-6	81566-1	1.53 (70°F)
B-7	8866-1	1.53 (77°F)
B-8	81966-1	1.56 (45°F)
B-9, B-10	8866-1	
	81566-1	1.53 (70°F)
	81966-1	
B-11, B-12	82366-1, 2	1.57 (70°F)
B-13, B-14	82366-2,3	1.55 (84°F)
B-15	63066-1, 2	
	72566-1, 2	1.54 (77°F)
	8366-1, 2	

**CONFIDENTIAL****2.4 Theoretical Performance of MONEX DW**

(C) Theoretical performance calculations were performed by the Air Force Rocket Propulsion Laboratory, Edwards Air Force Base, for MONEX DW 25 G.4-M1 and the MONEX DW/C<sub>2</sub>F<sub>3</sub> bipropellant system. These data are summarized in Tables III and IV. As the composition of the MONEX DW to be used in the current program is fixed, the data presented here is limited to that for the formulation MONEX DW 25 G.4-M1. Theoretical performance of MONEX DW as a function of composition is presented in Reference 1.

(C) Theoretical specific impulse of MONEX DW 25 G.4-M1 for both shifting and frozen equilibrium as a function of chamber pressure is presented in Figure 2. The difference in specific impulse for shifting equilibrium and frozen conditions amounts to 11 units of specific impulse (4 percent) at a chamber pressure of 1,000 psia. At the same pressure, the separation for the MONEX A monopropellant amounts to only 1 unit of specific impulse. It thus appears that achievement of chemical and phase equilibrium throughout the combustion and expansion process will be much more important for MONEX DW than MONEX A in order to obtain good performance.

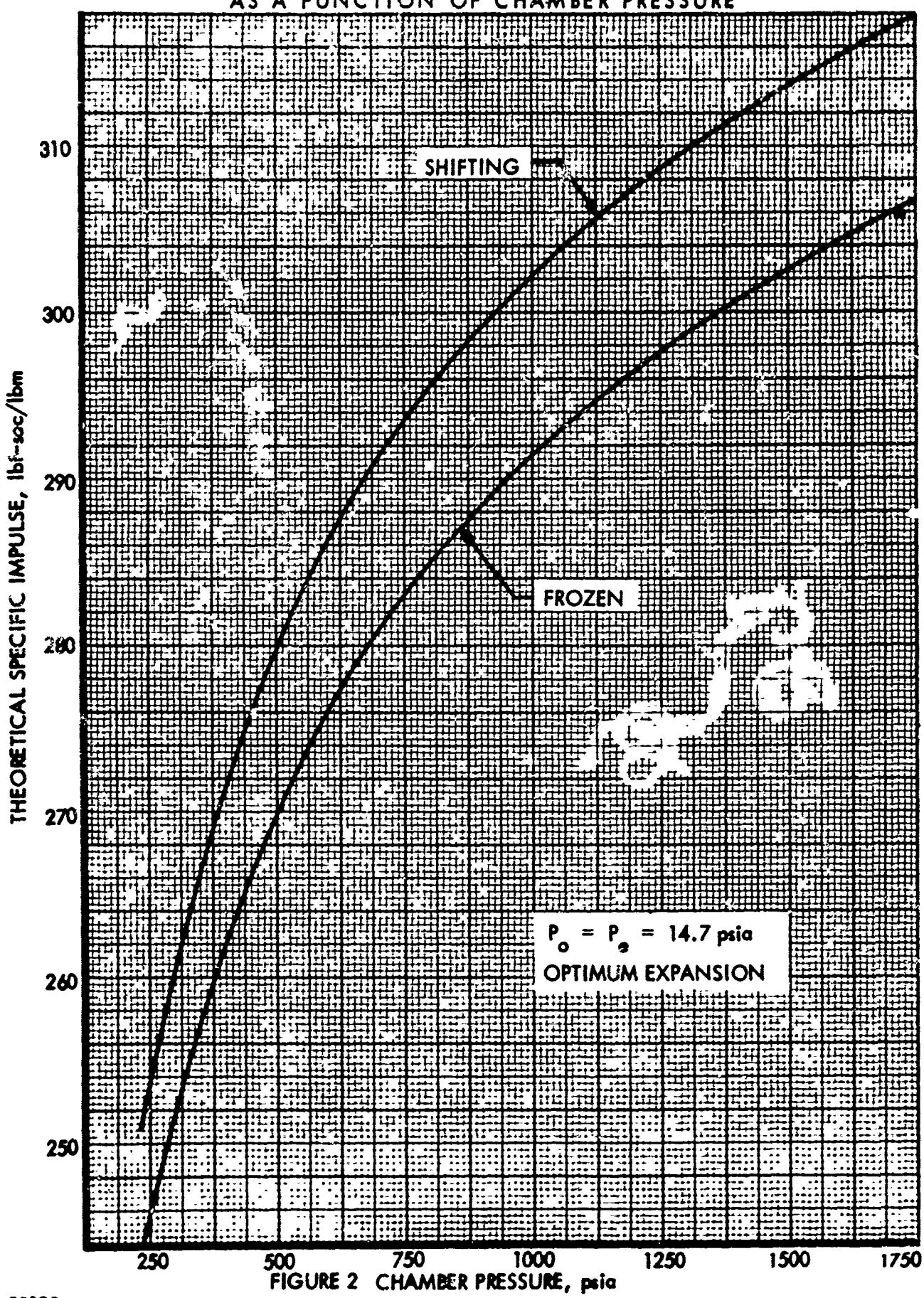
(C) Figure 3 illustrates the variation in theoretical chamber, throat, and exit plane temperatures as a function of chamber pressure. Although the theoretical chamber temperature is above the melting point of beryllium oxide, in practice, high combustion efficiency and low heat losses will be necessary to ensure that all the BeO is present in the chamber in molten form. It is estimated that a  $c^*$  efficiency of greater than 96.5 percent would be required to ensure the presence of BeO in molten form. With small, low efficiency engines, it may be expected that combustion of beryllium metal may proceed primarily via a gas diffusion method through a semi-porous beryllium oxide coating rather than by a mechanism involving a molten BeO coating. Although MONEX DW does possess a lower flame temperature than most beryllium containing propellant systems now undergoing investigation, it has been shown under the previous monopropellant program (Reference 1) that high conversion of beryllium to beryllium oxide can be obtained with this propellant in spite of its somewhat low flame temperature. Numerous studies have been conducted concerning the nature of the reaction occurring at beryllium metal surfaces in the presence of oxygen, water, nitrogen, and carbon dioxide (References 6, 7, 8, and 9). Although these studies have been performed at considerably lower temperatures (generally at less than 1,000°C) than found in normal rocket engines, they indicate

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MONEX DW 25G.4-M1 THEORETICAL SPECIFIC IMPULSE  
AS A FUNCTION OF CHAMBER PRESSURE



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MONEX DW 25G.4-M1  
THEORETICAL STATION TEMPERATURES  
AS A FUNCTION OF CHAMBER PRESSURE

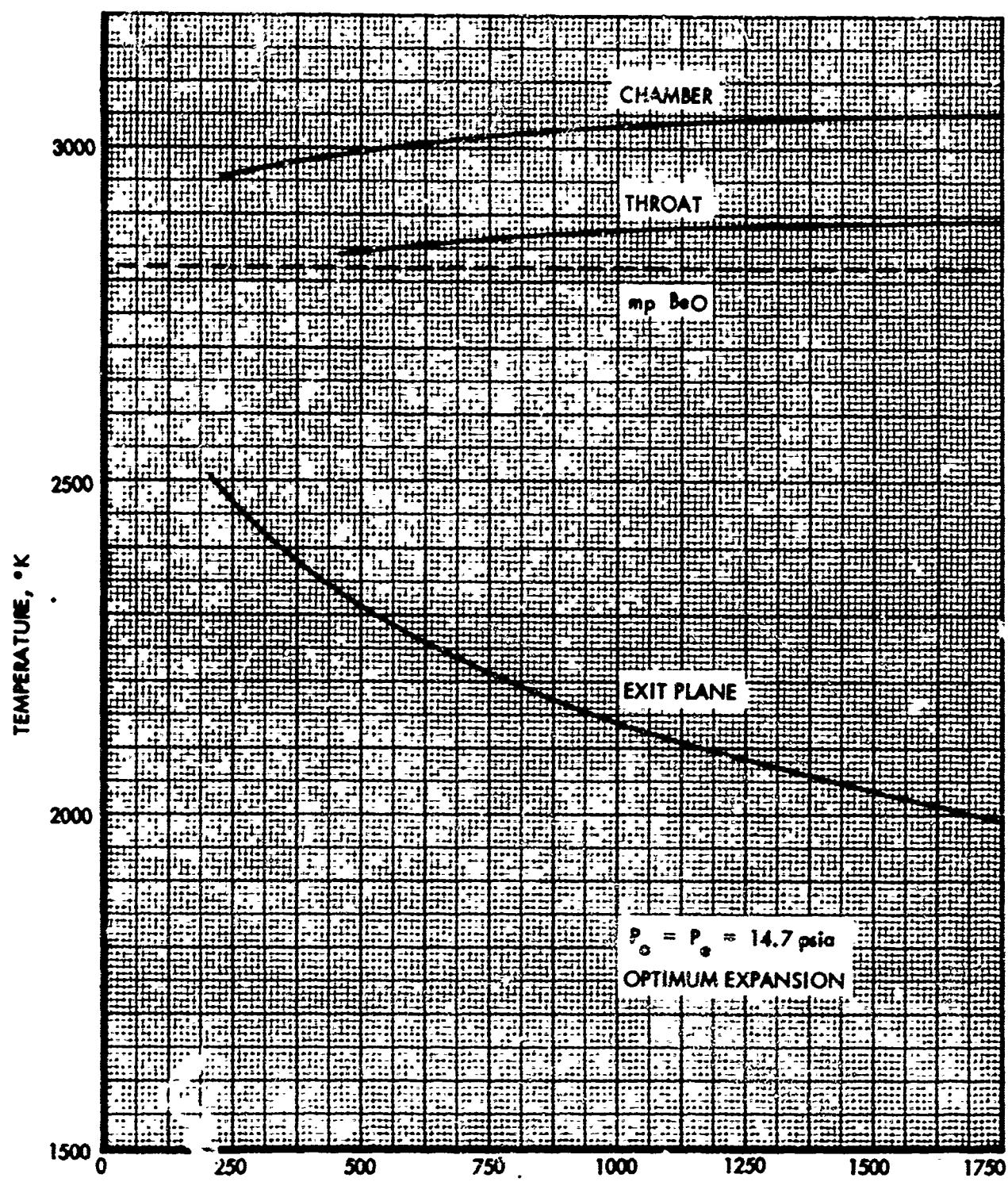


FIGURE 3 CHAMBER PRESSURE, psia

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TABLE III  
THEORETICAL PERFORMANCE OF MONEX DW 25 G.4-M1

$P_c$ psia	$I_s$ lbf-sec/lbm Shifting	lbf-sec/lbm Frozen	$c^*$ ft/sec	$T_c$ °K	$T_e$ °K	$A_e/A_t$	$C_F$
250	254.2	245.8	---	2962	2475	3.829	1.431
500	280.1	270.1	5674.6	3000	2319	6.506	1.588
750	293.4	282.9	5683.6	3021	2217	8.869	1.661
1000	302.1	291.3	5689.3	3034	2142	11.071	1.709
1250	308.5	297.6	5693.5	3045	2083	13.160	1.743
1500	313.5	302.6	5696.8	3052	2035	15.165	1.770
1750	317.5	306.6	5699.5	3059	1994	17.105	1.792

TABLE IV  
THEORETICAL PERFORMANCE OF THE SYSTEM MONEX DW 25 G.4-MI/CHLORINE TRIFLUORIDE

MONEX D Weight Percent	P <sub>c</sub> psia	I <sub>s</sub> lbf-sec/lbm Shifting	I <sub>s</sub> lbf-sec/lbm Frozen	C* ft/sec	T <sub>c</sub> °K	T <sub>e</sub> °K	A <sub>e</sub> /A <sub>t</sub>	C <sub>F</sub>
16.67	1000	222.7	204.9	4448.2	2829	1700	9.405	1.611
20.00	1000	243.1	228.3	4895.7	3320	1843	9.046	1.597
25.00	1000	267.2	252.2	5379.4	3873	2049	8.760	1.598
33.33	1000	278.2	256.8	5481.4	3867	2496	9.994	1.633
50.00	1000	285.5	265.5	5553.0	3664	2596	10.832	1.654
55.55	1000	286.9	269.3	5566.7	3587	2543	10.920	1.658
62.50	1000	288.9	273.5	5583.4	3487	2478	11.009	1.665
71.43	1000	291.7	278.4	5607.4	3366	2395	11.079	1.674
83.33	1000	295.8	284.2	5641.2	3218	2287	11.111	1.687
90.90	1000	298.6	287.6	5663.3	3130	2220	11.103	1.697
16.67	500	206.5	191.4	4402.7	2731	1795	5.571	1.509
20.00	500	226.3	214.7	4863.9	3253	1952	5.339	1.497
25.00	500	249.8	235.7	5347.8	3783	2287	5.335	1.503
33.33	500	257.7	239.1	5435.0	3755	2665	5.989	1.525
50.00	500	263.5	246.3	5509.5	3562	2722	6.306	1.539
55.55	500	264.9	249.8	5527.2	3496	2670	6.362	1.542
62.50	500	266.8	253.6	5548.5	3407	2619	6.421	1.547
71.43	500	269.5	258.1	5577.1	3298	2546	6.476	1.555
83.33	500	273.7	263.4	5617.5	3165	2451	5.512	1.568
90.91	500	276.5	266.5	5643.4	3086	2391	6.517	1.577

TABLE IV (Cont'd)  
THEORETICAL PERFORMANCE OF THE SYSTEM MONEX DW 25 G.4-M1/CHLORINE TRIFLUORIDE

MONEX D Weight Percent	P <sub>c</sub> psia	I <sub>s</sub> lbf-sec/lbm Shifting	I <sub>s</sub> lbf-sec/lbm Frozen	C* ft/sec	T <sub>c</sub> °K	T <sub>e</sub> °K	A <sub>e</sub> /A <sub>t</sub>	C <sub>F</sub>
16.67	250	187.7	175.7	4356.5	2638	1883	3.354	1.386
20.00	250	206.9	198.6	4836.1	3196	2067	3.210	1.376
25.00	250	228.6	216.0	5313.4	3692	2564	3.321	1.384
33.33	250	233.7	218.6	5387.1	3645	2810	3.532	1.396
50.00	250	238.1	224.6	5464.4	3462	2819	3.719	1.402
55.55	250	239.4	227.6	5486.4	3405	2780	3.752	1.404
62.50	250	241.2	231.0	5511.4	3326	2729	3.789	1.408
71.43	250	243.8	235.0	5545.0	3229	2667	3.826	1.415
83.33	250	247.8	239.7	5591.5	3109	2585	3.856	1.426
90.91	250	250.7	242.5	5621.1	3038	2535	3.866	1.435

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that even in this region breakaway temperatures are obtained at which point the oxide or combustion product coatings fail to provide protection against rapid metal reaction. Water vapor has been shown to react more rapidly than dry oxygen with beryllium metal surfaces in these temperature regions. It may, therefore, be possible that with the considerably higher temperatures and high metal surface areas to be found in a rocket propellant, reaction rates may be sufficiently high that good combustion efficiency may be obtained, even though no molten oxide is involved. At these temperatures the metal will be molten (Be melting point - 1556°K) and the vapor pressure and rate of vaporization of Be metal at these temperatures may be expected to play a significant role. If the trends observed at lower temperatures hold true in the high temperature region, the high water content of the MONEX DW propellant may play a significant role in the nature of the observed combustion.

(C) Figure 4 presents a comparison of the theoretical composition of the gas phases present in both the combustion chamber and at the nozzle exit plane. Only a slight difference occurs in the total moles of gas present and change in relative distribution of the various species is minor. Hydrogen and nitrogen are the predominant species present. According to the calculations, most of the water originally present in the propellant will be consumed in the formation of beryllium oxide.

(C) Theoretical specific impulse of the MONEX DW/ClF<sub>3</sub> system for both shifting and frozen equilibrium as a function of composition is shown in Figure 5. Using a ClF<sub>3</sub> ignition technique, the MONEX DW engine is actually functioning as a bipropellant engine for a short period prior to shut-off of the ClF<sub>3</sub>. During this period, it may be possible to determine the performance of the engine in the bipropellant mode and make comparisons with the monopropellant mode.

## 2.5 Test Program

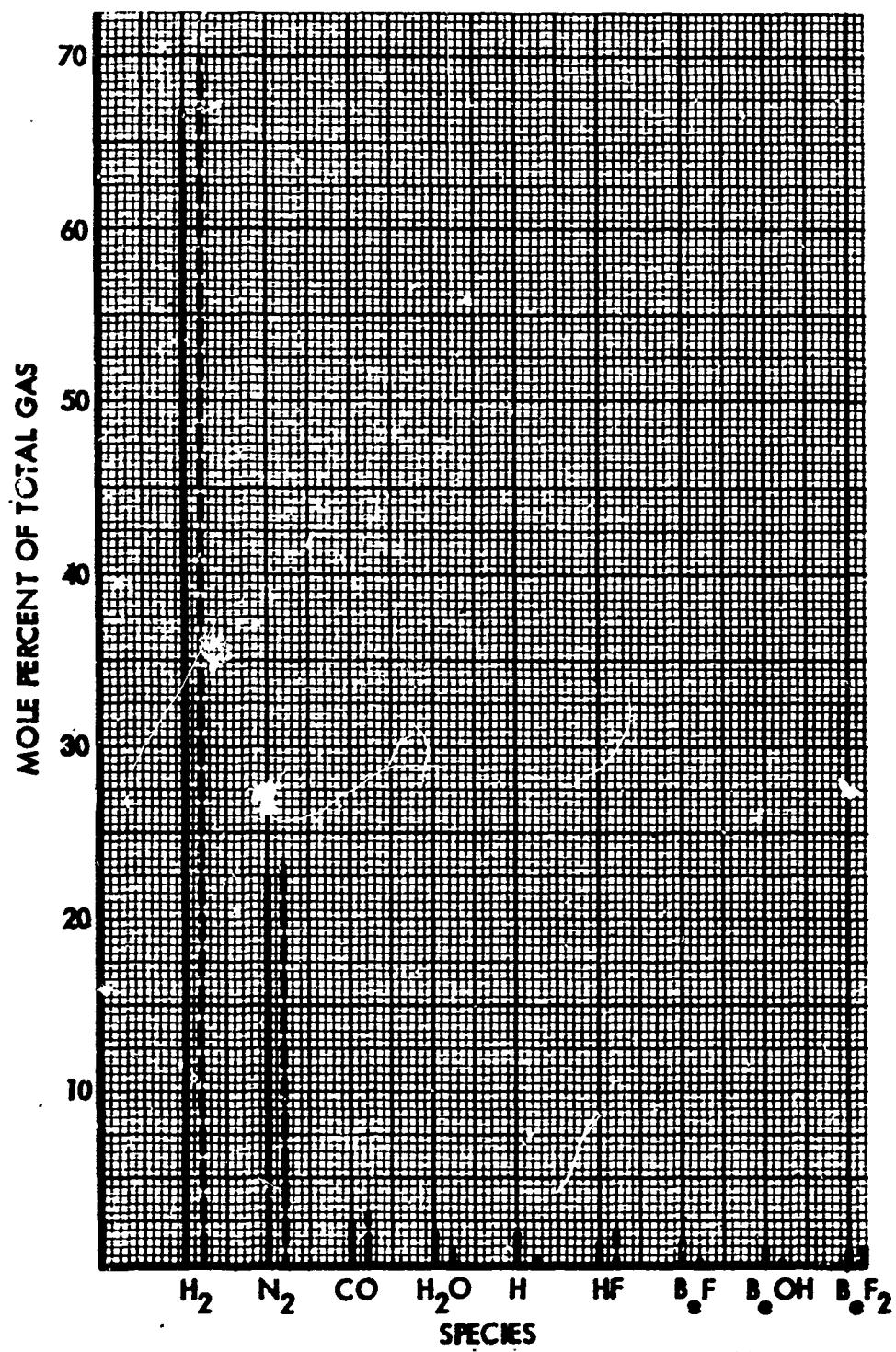
(U) During this report period, the MONEX A checkout tests and the MONEX A Baseline Test series were completed, thereby completing all MONEX A testing. A discussion of the test hardware, baseline test installation, and test results are presented in the following sections.

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(C) MONEX DW 25G.4-M1

## GAS COMPOSITION OF CHAMBER AND EXHAUST GASES



$P_c = 1000$  psia      — CHAMBER SPECIES  
 $P_c = P_e = 14.7$  psia      --- EXHAUST SPECIES

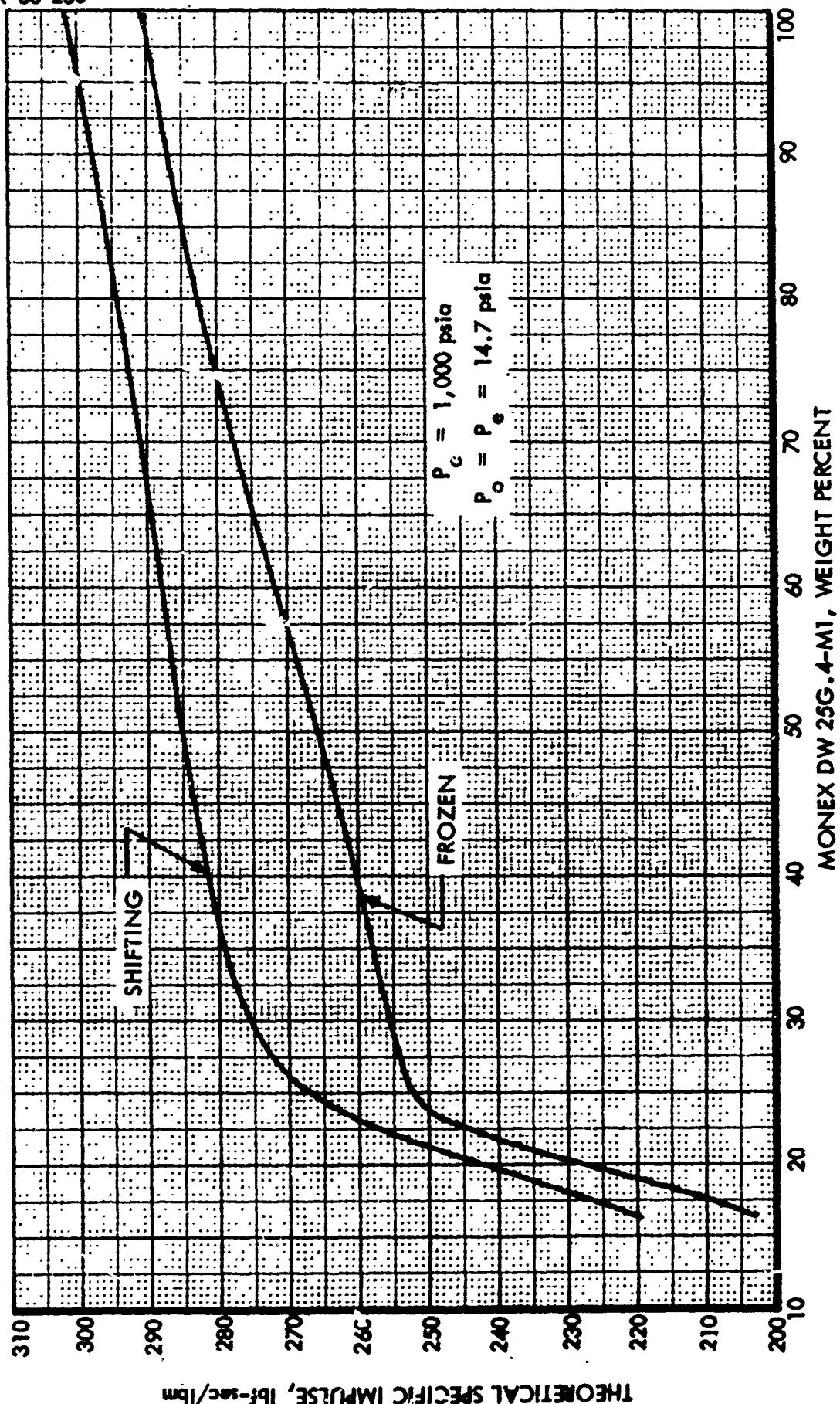
FOR 100 gm SAMPLE

TOTAL CHAMBER GAS = 4.78 moles

TOTAL EXHAUST GAS = 4.70 moles

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MONEX DW 25G.4-MI / CHLORINE TRIFLUORIDE  
 THEORETICAL SPECIFIC IMPULSE AS A FUNCTION OF COMPOSITION



550%

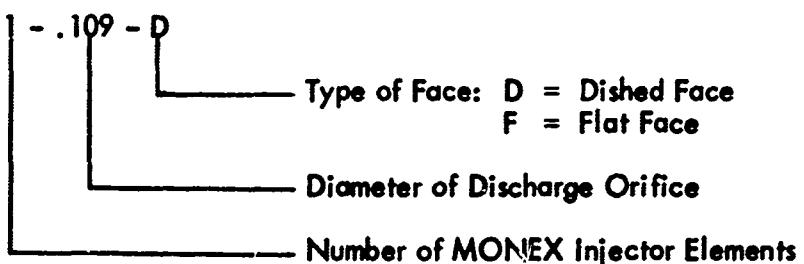
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2.5.1 Test Hardware:

(U) During the report period, four injector patterns were tested:

- a. A single element injector (1-xx-D)
- b. A dished face, two element injector (2-xx-D)
- c. A dished face four element injector (4-xx-D)
- d. A flat face four element injector (4-xx-F).

(U) These injectors are designated by the number of MONEX spray elements, the discharge orifice diameter, and the type of injector face (either flat or dished). Throughout this report a designation as follows is used:



(U) The above designation would be a single element injector with a 0.109 inch diameter discharge orifice and a dished face.

(U) Solid cone spray nozzles were used as the MONEX injector element(s) in each injector. The number of elements discussed above denotes the number of MONEX injector elements as each injector also employs a single  $\text{ClF}_3$  spray nozzle for ignition purposes.

(U) The single element dished face injector employs a central MONEX spray nozzle and an outer  $\text{ClF}_3$  spray nozzle. MONEX spray nozzles having discharge orifices of 0.109 inch and 0.156 inch diameter were tested in the single element injector. These injectors are designated as 1-.109-D and 1-.156-D, respectively.

(U) One of the factors known to influence spray droplet size of spray nozzles is the discharge orifice diameter. Droplet size increases with increasing orifice diameter. In an attempt to produce a spray pattern with a smaller droplet size, three multielement injectors incorporating smaller size spray nozzles were tested.

(U) The two element dished face injector employed two outer MONEX spray nozzles with a 0.04 inch diameter orifice and a central  $\text{ClF}_3$  spray nozzle. The MONEX spray nozzles were located 0.8 inch from the chamber centerline at an angle of 30° to the chamber axis. All dished face injectors incorporated a conical face with a 120° included angle. This injector is designated as the 2-.094-D injector.

(U) The dished face four element injector incorporated four MONEX spray nozzles with a 0.062 inch diameter orifice and one central  $\text{ClF}_3$  spray nozzle. The MONEX spray nozzles were located 0.8 inch from the chamber centerline at an angle of 30° to the chamber axis. This injector is designated as 4-.062-D.

(U) The flat face four element injector consisted of four outer MONEX spray nozzles with a 0.067 inch diameter orifice and a central  $\text{ClF}_3$  spray nozzle. The MONEX spray nozzles were located 0.85 inch from the chamber centerline and were parallel to the chamber axis. The designation of this injector is 4-.067-F.

(U) During the initial two baseline tests, Rokide coated (0.020 inch thick) mild steel nozzles were tested. The erosion rate experience with these nozzles was an order of magnitude greater than previously experienced with ATJ graphite throat inserts. Following Baseline Test No. 2, ATJ graphite throat inserts were employed for the remainder of the Baseline Test Program.

#### 2.5.2 Test Installation

(U) During this report period, the MONEX DW test facility was completed and placed in operation. A photograph of the MONEX DW test installation is presented in Figure 6. This test installation was used for the MONEX A Baseline Test series and will be used for all MONEX DW tests. The propellant feed systems, both MONEX and the  $\text{ClF}_3$  ignition system, are similar to those of the checkout test installation, and conform to the schematic diagram shown in Figure 7 of Reference 3.

(U) The chief difference in the checkout test installation and the MONEX DW test installation was the addition of a thrust stand and an exhaust chamber to the MONEX DW test installation. The thrust stand is of the parallelogram type and employs Bendix Flexural Pivots as flexures. The stand is calibrated by applying known weights, acting over a 5:1 pulley through the centerline of thrust.

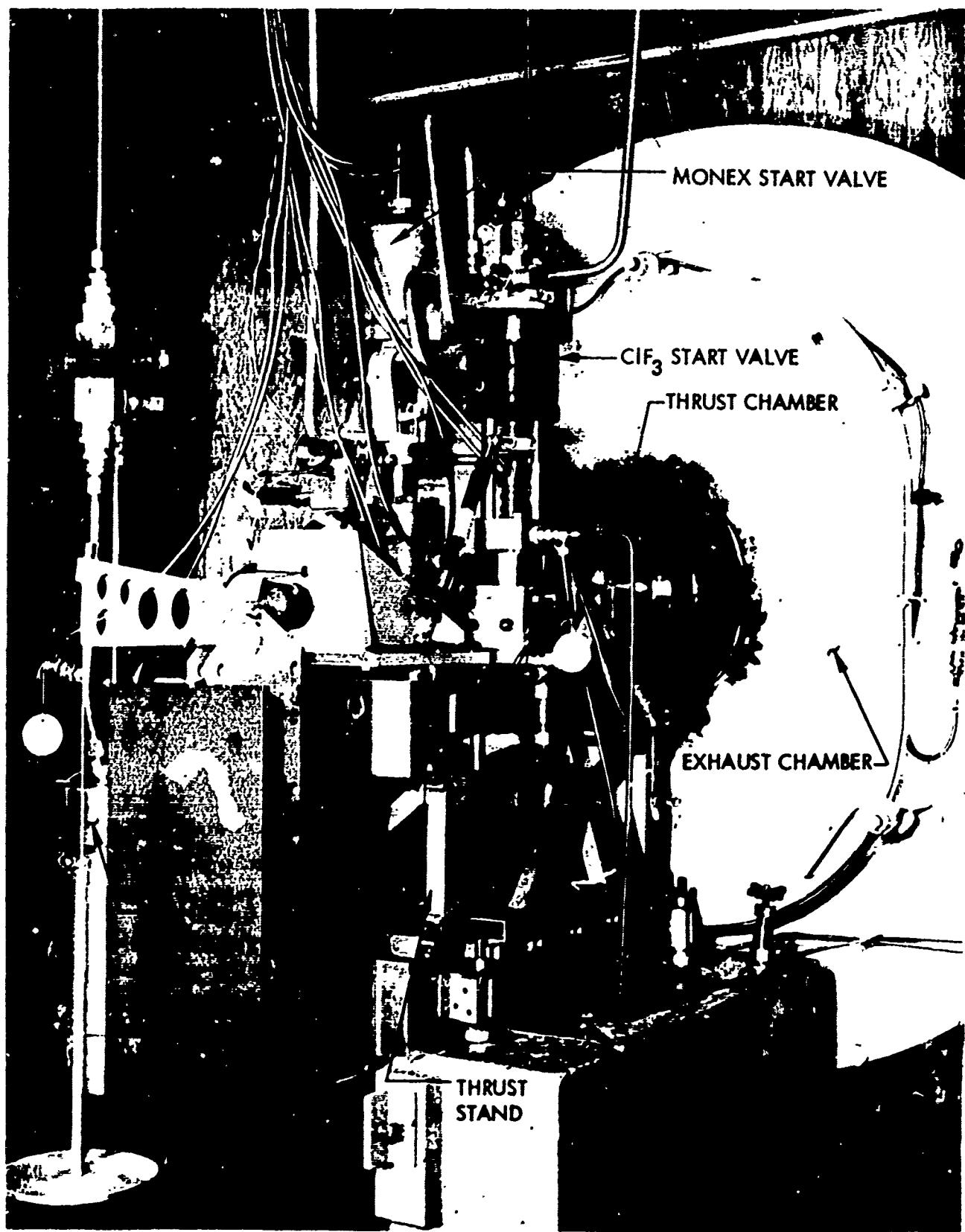


FIGURE 6 MONEX DW TEST INSTALLATION

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(C) A 50 inch diameter by 40 foot long exhaust chamber equipped with a bank of Ultra-Air filters is employed to contain and filter solid particles from the thrust chamber exhaust gases. The thrust chamber is mounted externally to the exhaust chamber (see Figure 6). A rubber wiper around the nozzle provides an effective exhaust gas seal without impairing thrust measurements. Prior to each test firing, the exhaust chamber is purged with nitrogen to reduce the oxygen content and prevent accumulation of an explosive mixture with the exhaust gases which contain a high hydrogen content.

#### 2.5.3 Data Reduction Techniques

(U) The test data presented in Tables V and VI were normally taken just prior to shutdown, the actual time at which the test records were reduced is presented under the column labeled "Data Time". Test duration was taken as the time interval from the fire switch on signal to propellant valve closure.

(U) Absolute chamber pressure was obtained by adding barometric pressure to the measured gauge chamber pressure. Injector pressure drop ( $\Delta P_{inj}$ ) was obtained from the difference between injector inlet pressure and chamber pressure. The propellant flow rate was calculated from the flowmeter frequency output, the calibration factor, and the propellant density.

(U) Two values of post test nozzle throat area are presented: one with the combustion slag in place (labeled "slag intact"), and the second with the slag deposit removed from the throat area (labeled "slag removed"). These values of throat area were obtained from an average throat diameter calculated from a minimum of four equally spaced readings measured with an optical comparator. Since the throat area increases during a test, it is unlikely that an oxide deposit is present during a firing, as this would require erosion of the graphite nozzle under the slag deposit. Therefore, it is believed slag deposit in the throat is formed during the shutdown transient and that the actual throat area is that measured with the slag deposit removed. Removal of this slag deposit is extremely difficult without also removing a small amount of graphite from the throat. The throat area measured with the slag deposit removed is thus somewhat questionable. The estimated error in throat area resulting from difficulties in removing the slag deposit is less than 3%.

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TABLE V  
(U) PRELIMINARY DATA SUMMARY  
MONEX A CHECKOUT TEST SERIES (1)  
(3)

Test No.	Injector #	Date	P <sub>c</sub> (psia)	ΔP <sub>inj</sub> (psi)	ψ	(lb/sec)	Throat Area			Duration (sec)	Remarks
							Coating Intact (in <sup>2</sup> )	Coating Removed (in <sup>2</sup> )	c <sup>*</sup> (ft/sec)		
10	1-.109-D	3.7	715	553	1.325	.2246	.2507(6)	4190	88.1	1.9	3.96
11	1-.109-D	3.9	631	802	1.440	.2620	.2884	4070	85.6	3.8	3.98
12	1-.156-D										
13	1-.156-D									2.6	
14	2-.094-D										1.3
15	2-.094	2.6	932	523	1.884	.2312	.2606	4150	87.2	8.6	2.82

NOTES: (1) All tests conducted with nominal 300 in L<sup>2</sup> chamber

(2) Injector designation: 1-.109-D

Type of face: D = Dished, F = Flat  
Spray nozzle discharge orifice dia. (in)  
Number of MONEX injector elements

- (3) Throat areas presented are post test nozzle throat areas with combustion slag intact and removed
- (4) c<sup>\*</sup> values are based upon throat area with coating removed
- (5) Magnitude of chamber pressure oscillations
- (6) Estimated throat area based on average coating thickness of 0.0095 in

TABLE VI  
(U) PRELIMINARY DATA SUMMARY  
MONEX A BASELINE TEST SERIES

Test No.	Injector (1) No.	L <sub>c</sub> (in)	Date Time (sec)	P <sub>c</sub> (psi)	ΔP <sub>in</sub> (psi)	ΔP <sub>in</sub> (psi)	Thr <sub>c</sub> (lb/sec)	Thr <sub>c</sub> Coating removed (lb/sec)	Thr <sub>c</sub> Coating in tact (lb/sec)	C <sub>c</sub> (lb/sec) (% Thr <sub>c</sub> )	F <sub>c</sub> (lb) (% Thr <sub>c</sub> )	I <sub>cp</sub> (lb-sec) (% Thr <sub>c</sub> )	I <sub>cp</sub> (lb-sec) (% Thr <sub>c</sub> )	Theo <sub>c</sub> (lb)	ΔP <sub>c</sub> (lb) (% P <sub>c</sub> )	Duration (sec)	Remarks		
1,2,3	4-042-D	300																P <sub>c</sub> oscillations of up to $\pm 400$ psi caused by combustion sleg coating of injector spray nozzles	
4	1-109-D	300	1.15	719	451	1.167	1,032	1.197 <sup>(1)</sup>	39.30	82.4	207	177	231.5	76.5	9,995	4.2	1.24	P <sub>c</sub> = 940 psi during bipropellant phase, unstable monopropellant combustion: P <sub>c</sub> = 750 $\pm$ 400 psi	
5	4-047-F	300	1.03	933	375	1.408	1,960	0.211 <sup>(2)</sup>	40.50	85.1	309	192	238.8	80.4	9,921	9.4	1.22	P <sub>c</sub> = 940 psi during bipropellant phase, combustion caused by combustion sleg coating of injector spray nozzles	
6	4-047-F	150	1.03	993	430	1.718	2,003	0.215 <sup>(2)</sup>	40.20	84.3	330	192	239.4	80.2	8,985	10.6	1.24	P <sub>c</sub> = 940 psi during bipropellant phase, combustion caused by combustion sleg coating of injector spray nozzles	
7	4-047-F	75																P <sub>c</sub> = 940 psi during bipropellant phase, combustion caused by combustion sleg coating of injector spray nozzles	
8	1-109-D	75	1.00	817	618	1.411	2,043	0.219 <sup>(2)</sup>	40.90	84.0	233	179	236.5	75.7	8,976	4.8	1.22	P <sub>c</sub> = 940 psi during bipropellant phase, combustion caused by combustion sleg coating of injector spray nozzles	
9	1-109-D	150	1.10	774	438	1.534	2,148	0.220 <sup>(2)</sup>	37.20	78.1	276	180	234.4	76.8	8,547	-	1.2	P <sub>c</sub> = 940 psi during bipropellant phase, combustion caused by combustion sleg coating of injector spray nozzles	
10	1-109-D	150	1.15	355	434	1.234	3,475	0.370 <sup>(2)</sup>	35.00	72.9	175	142	211.9	67.0	5,721	5.5*	1.22	P <sub>c</sub> = 940 psi during bipropellant phase, combustion caused by combustion sleg coating of injector spray nozzles	
11	4-047-F	150																P <sub>c</sub> = 940 psi during bipropellant phase, combustion caused by combustion sleg coating of injector spray nozzles	
12	1-109-D	150	1.40	1,222	813	1.531	1,420	0.150 <sup>(2)</sup>	40.50	85.0	310	202	244.4	82.7	11,63	2.6	1.48	P <sub>c</sub> = 940 psi during bipropellant phase, combustion caused by combustion sleg coating of injector spray nozzles	
13	1-109-D/F	150	1.15	794	661	1.435	2,103	0.221 <sup>(2)</sup>	39.50	83.0	245	185	235.2	78.7	9,076	6.6**	1.24	P <sub>c</sub> = 940 psi during bipropellant phase, combustion caused by combustion sleg coating of injector spray nozzles	
14	4-047-F	150	0.6	1,539	574	1.867	--	1.500	4,180	87.6	372	204	230.9	82.1	12,82	8.1	1.23	P <sub>c</sub> = 940 psi during bipropellant phase, combustion caused by combustion sleg coating of injector spray nozzles	
15	4-047-F	150	0.6	1,539	574	1.867	--	1.500	4,180	87.6	372	204	230.9	82.1	12,82	8.1	1.23	P <sub>c</sub> = 940 psi during bipropellant phase, combustion caused by combustion sleg coating of injector spray nozzles	

(1) Injector Designation:

4 - 042 - D Type of injector face, D = dished, F = flat

Spray nozzle discharge orifice diameter (in.)

No. MONEX injector elements

(2) Thrust Area: Thrust areas presented are post-test areas with coating removed

(3) C is based upon thrust area with coating removed

(4) Measured thrust reduced to compensate for higher than ambient exhaust tank pressure

(5) Theoretical I<sub>cp</sub> at test P<sub>c</sub> ambient pressure, Nozzle A<sub>0</sub>/A<sub>1</sub> and half angle

(6) Magnitude of chamber pressure oscillations

(7) Estimated thrust area based upon average combustion sleg deposit thickness of 0.0095 in.

(U) The value of the throat area with the slag deposit removed is not available for four tests. In these cases an average slag thickness from the remaining tests was used to calculate a throat diameter for these four tests and are so noted in the Data Tables. The slag thickness was reasonably uniform and varied from 0.005 inch to 0.016 inch and averaged 0.0095 inch. Using this average method, the inaccuracy in throat area should not exceed an additional 2%.

(U) The reported characteristic velocity,  $c^*$ , is based upon the throat area with the coating removed. Since this value of throat is somewhat questionable,  $c^*$  is also somewhat in doubt. Therefore, all performance discussions presented in this report are based upon specific impulse.

(U) The reported thrust is the measured value of thrust adjusted to compensate for the higher than ambient exhaust tank pressure. The exhaust tank pressure acts on a small area (approximately 1.5 inches<sup>2</sup>) between the nozzle outside diameter and nozzle exit diameter, and results in a small positive force included in the measured thrust. The actual thrust is obtained from:

$$F_{\text{actual}} = F_{\text{measured}} - P_a (A_n - A_e)$$

Where:

$F_{\text{measured}}$  = Measured thrust, lb

$P_a$  = Exhaust tank pressure, measured in psi above local ambient

$A_n$  = Area of nozzle normal to thrust axis, in<sup>2</sup>

$A_e$  = Nozzle exit area, in<sup>2</sup>

(U) The effect of the above adjustment is a reduction of approximately one pound in measured thrust.

(U) Specific impulse is based upon the actual thrust calculated from the above equation and the propellant flow rate. No other adjustments or corrections were applied to thrust or specific impulse.

(U) A value of theoretical specific impulse was calculated for the actual test conditions of chamber pressure, barometric pressure, nozzle expansion ratio, and nozzle half angle (15°). This value, reported under "Theoretical  $I_{sp}$ ", is based upon shifting equilibrium values of  $C_f$  and  $P_e/P_c$  versus  $A_e/A_c$  reported in Reference 3. The actual test nozzle expansion ratio is reported under " $A_e/A_t$ ".

(U) The magnitude of chamber pressure oscillations are reported as " $\Delta P_c$ ." These data were obtained from the magnitude of the peak-to-peak chamber pressure and the mean chamber pressure and are reported as  $\pm$  % of chamber pressure.

## 2.6 Test Results

### 2.6.1 MONEX A Checkout Tests

(U) During this report period, four MONEX A checkout tests (No. 12 through 15) were conducted which completed the MONEX A checkout test series. The purpose of these four tests was to investigate the effect of two injector variations on performance. The results of these tests and revised performance values for previously reported tests 10 and 11 are presented below. The data from these tests are summarized in Table V.

#### 2.6.1.1 Tests 10 and 11

(U) Tests 10 and 11 were conducted with the 1-.109-D injector. The MONEX spray nozzle employed during these tests was a Spraying Systems Company GD-9.5 Fulljet Nozzle with a 0.109 inch diameter discharge orifice. Characteristic velocities of 82.1 and 77.8% of theoretical were previously reported (see Reference 3) for tests 10 and 11. These data were based upon the throat area measured with the combustion slag deposit in the throat. The combustion deposit was later removed from the nozzle employed during Test No. 11 and the throat diameter measured. The characteristic velocity based upon this later measurement was 4070 ft/sec (85.6% of theoretical).

(U) The nozzle employed during Test 10 was also employed during Test No. 11, preventing the measurement of the nozzle coating thickness following Test 10 at a later date. An average coating thickness (0.0095 inch) from all tests during which the coating thickness was

determined was used to estimate a throat area for Test No. 10. This estimate resulted in a  $c^*$  of 4,190 ft/sec (88.2% of theoretical).

#### 2.6.1.2 Tests 12 and 13

(U) Tests 12 and 13 were conducted with a single element injector (1-156-D) employing a higher capacity MONEX spray nozzle than employed during Tests 10 and 11. The purpose of installation of this larger spray nozzle (Spraying Systems Company GD-15 with a 0.156 diameter orifice) was to increase the MONEX A flow rate over tests 10 and 11 and allow operation at higher chamber pressures. During Test No. 12, a low frequency instability (140 to 220 cps) developed after 0.6 sec of operation in the bipropellant mode at a chamber pressure of 1,075 psia. The magnitude of the oscillation increased to  $\pm 400$  psi during the transition to monopropellant operation. Combustion appeared to cease at a time approximately corresponding to completion of the transition to monopropellant operation.

(U) Test 13 was conducted under the same initial conditions as Test No. 12. There was no evidence of a similar combustion instability during Test No. 13; however, after 0.3 sec of operation, a burst diaphragm on the chamber ruptured. This occurred while operating at a chamber pressure of 1,067 psia. The diaphragm was rated to burst at 2,200 psia in the event of severe overpressurization. As a result of rupture of the diaphragm and subsequent erosion of the burst diaphragm retainer, the effective throat area steadily increased, causing chamber pressure to decrease. At completion of the transition to monopropellant operation chamber pressure was 640 psia. Chamber pressure then rapidly decreased, and combustion ceased prior to termination of MONEX A flow.

(U) As a result of these difficulties, combustion efficiency data was not obtained from Tests 12 and 13. The exact cause of the instability during Test No. 12 is unknown. It could be the result of either a feed system oscillation problem or possibly a poor spray pattern obtained with the larger spray nozzle employed, and subsequent combustion time lag during these two tests. Combustion ceased during Tests 12 and 13.

Sustained combustion had previously been achieved under similar conditions with a smaller spray nozzle. This failure to sustain combustion during Tests 12 and 13 lends support to the possibility of a poor spray pattern obtained with the larger spray nozzle.

(U) Subsequent tests during the Baseline Test Series indicated that combustion instabilities could be the result of a poor injector spray pattern. (See Paragraph 2.6.2.) These later tests lend support to the possibility of a poor spray pattern causing the instability observed during Test No. 12.

#### 2.6.1.3 Tests 14 and 15

(U) Checkout tests 14 and 15 were conducted with the two element injector (2-.109-D). This injector employs two Spraying Systems Company GD-6.5 Fulljet Nozzles with 0.094 inch diameter discharge orifices. Test 14 was prematurely terminated during bipropellant operation after 1.3 seconds by a control system malfunction. During Checkout Test 15, a  $c^*$  of 87.2% of theoretical was measured at a chamber pressure of 932 psia. This test completed the MONEX A Checkout Test Series.

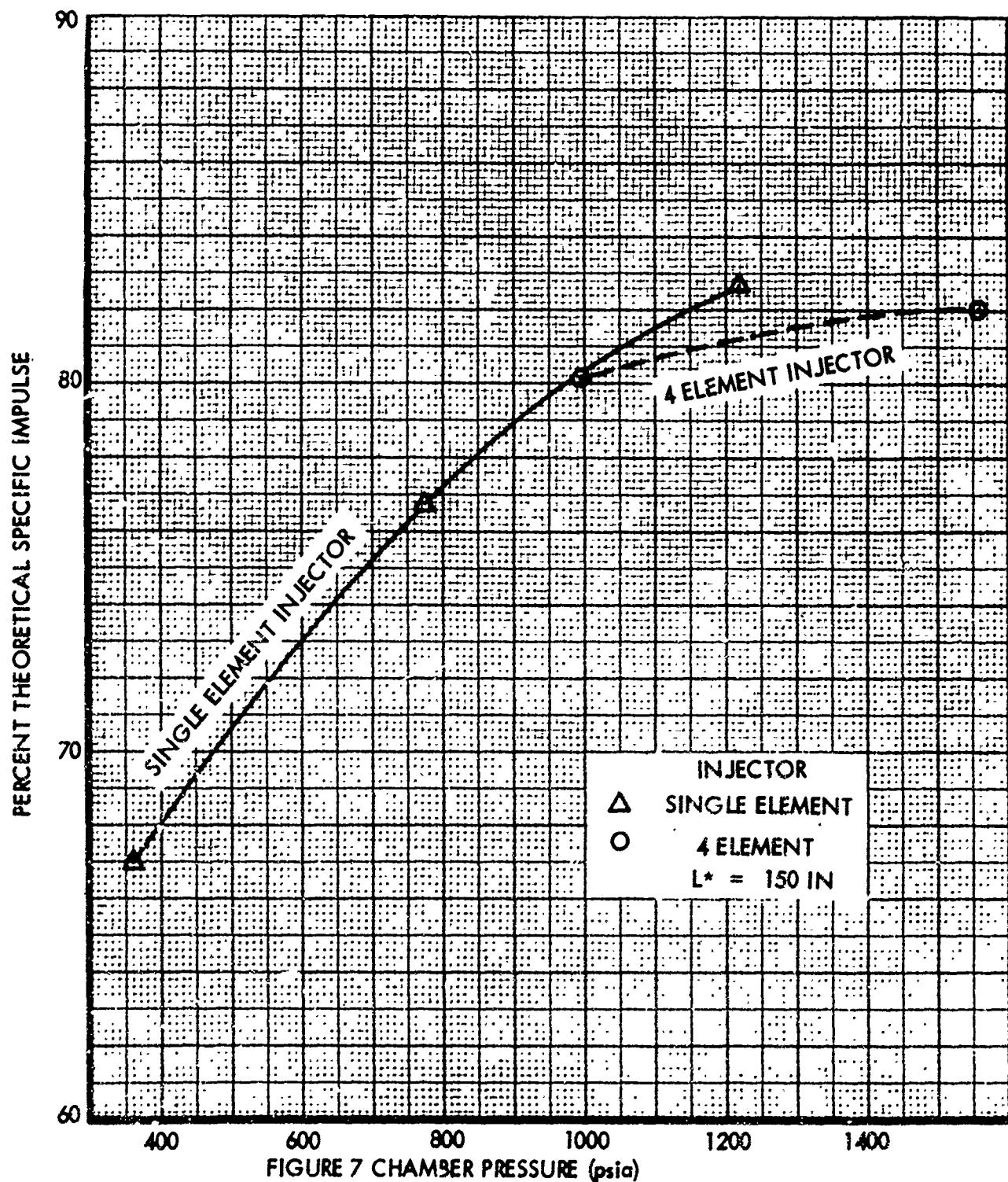
#### 2.6.2 Baseline Test Series

(U) The purpose of the MONEX A baseline test series, conducted during this report period, was: the investigation of the effect of chamber pressure and  $L^*$  on performance of a metallized monopropellant and to provide a performance baseline for future MONEX DW tests. A total of 15 tests, B-1 through B-15, were conducted during the Baseline Test Series employing the MONEX DW test facility. The results of these tests are summarized in Table VI and Figures 7 through 9.

(U) Three injector patterns were employed during the MONEX A Baseline Test Series. They were: the 4-.062-D injector (Tests B-1 through B-3), the 1-.109-D injector (Tests B-4, B-8, B-9, B-10, B-12, and B-13), and the 4-.067-F injector (Tests B-5, B-6, B-7, B-11, B-14, and B-15).

(U) As a result of difficulties experienced with the four element injectors, the original ten test baseline test matrix was modified to consist of five tests with two injectors (single element and four element flat face injector). The five tests

MONEX A  
VARIATION OF SPECIFIC IMPULSE  
WITH CHAMBER PRESSURE



VARIATION OF SPECIFIC IMPULSE  
WITH  
CHAMBER PRESSURE

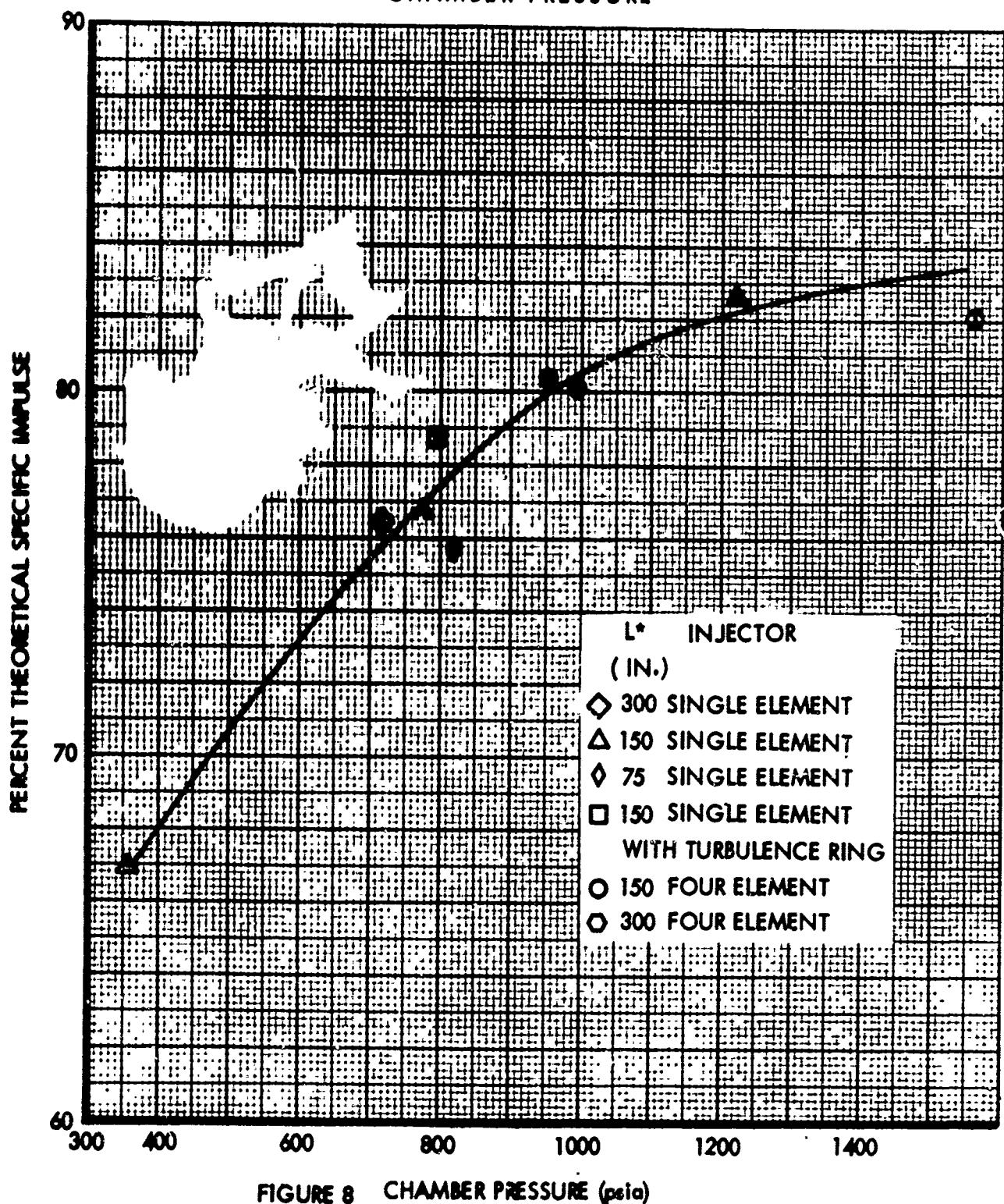
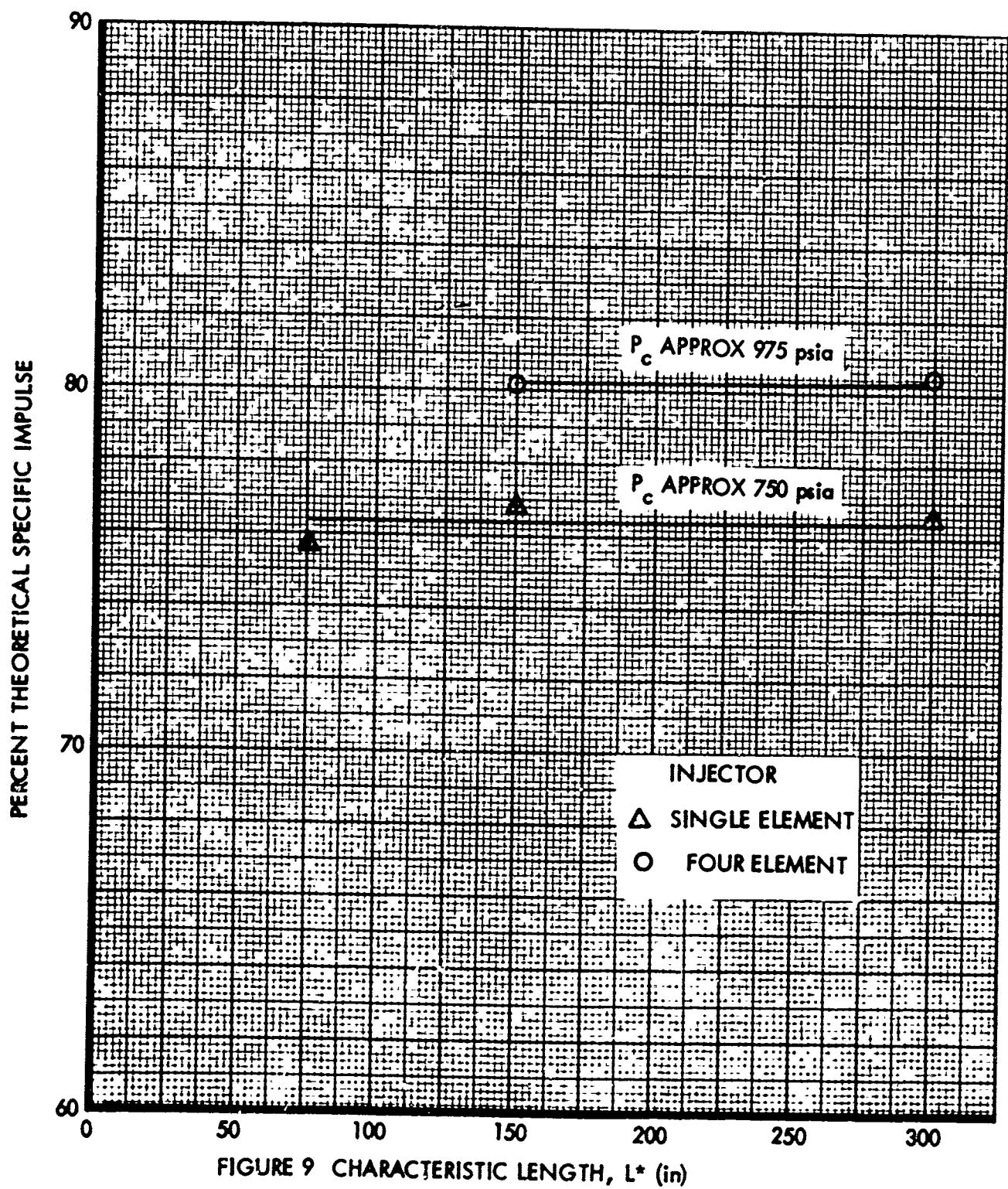


FIGURE 8 CHAMBER PRESSURE (psia)

VARIATION OF SPECIFIC IMPULSE  
WITH CHARACTERISTIC LENGTHFIGURE 9 CHARACTERISTIC LENGTH,  $L^*$  (in)

with each injector consisted of three tests at constant chamber pressure to investigate the effect of  $L^*$ 's of 75, 150, and 300 inches on performance. These tests were followed by two tests at a constant  $L^*$  of 150 inches to investigate the effect of chamber pressure on performance. One additional test with the single element injector was included to investigate the effect of a turbulence ring on performance. The results of these tests are presented in the following paragraphs and discussed by subject matter in Paragraph 2.7.

#### 2.6.2.1 Tests B-1 through B-3

(U) The injector configuration selected for the initial baseline tests was the four element, dished face injector (4-.062-D). This injector employs four Spraying Systems Company, GD-3 Fulljet nozzles (0.062 inch diameter discharge orifice) as the MONEX injector elements. The discharge orifice of the GD-3 nozzle was smaller than that of any similar spray nozzles previously employed. The smaller spray nozzles were selected to reduce the spray droplet diameter and possibly increase combustion efficiency.

(U) During baseline Tests 1 through 3, stable combustion, with chamber pressure oscillations of less than  $\pm 5\%$ , was obtained during bipropellant operation at chamber pressures from 630 psia (Test B-1) to 990 psia (Test B-3). The MONEX injector pressure drop during this time was approximately 500 psi. Immediately upon termination of the  $\text{ClF}_3$  flow, random oscillations began to occur in chamber pressure. During Test B-3, these oscillations ranged from  $\pm 100$  to  $\pm 400$  psi at a nominal chamber pressure of approximately 850 psia. Similar chamber pressure oscillations of a lower magnitude occurred during the monopropellant phase of baseline Tests B-1 and B-2.

(U) Following Tests B-1 through B-3, a combustion slag deposit was observed to partially obscure each spray nozzle orifice. Post firing injector spray tests using MONEX A as the flow media were conducted with the slag deposit in place. These slag deposits were found to alter the spray pattern. A large number of individual propellant streams were formed as the MONEX impinged upon the slag deposit and only a

portion of the MONEX developed into a spray. Similar slag deposits were not observed during previous tests with a single element injector. These slag deposits are believed to have been a contributing factor to the chamber pressure oscillations and would most likely prevent the attainment of high combustion efficiency. The stable operation observed during bipropellant combustion indicates that the MONEX feed system may not have been the primary cause of the monopropellant combustion oscillations.

#### 2.6.2.2 Test B-4

(U) Test B-4 was conducted with the 1-.109-D injector employed during checkout tests 9, 10, and 11. Stable monopropellant combustion was achieved during each of these previous tests (chamber pressure oscillations less than  $\pm 5\%$ ). Stable monopropellant combustion was again achieved during Test B-4. The delivered specific impulse measured during this test was 76.5% of theoretical shifting equilibrium, at a chamber pressure of 719 psia.

#### 2.6.2.3 Tests B-5 through B-7

(U) The stable monopropellant combustion achieved with the single element injector during Test B-4 indicated that the combustion instability observed during Tests B-1 through B-3 was associated with the four element dished face injector (4-.062-D). It was believed that the combustion instability associated with the 4-.062-D injector was caused by the combustion slag deposits observed over the injector spray nozzles following each test. In an attempt to minimize the formation of these combustion slag deposits, a four element flat face injector (4-.067-F) was fabricated and tested. The formation of combustion slag deposits over the injector orifices were greatly reduced with the flat face injector and the combustion stability significantly improved.

(U) Tests B-5 through B-7 comprised an  $L^*$  survey over the range of 300 in. (Test B-5) to 75 in. (Test B-7), at a nominal chamber pressure of 1,000 psia, with the 4-.067-F injector. Tests B-5 and B-6 resulted in delivered specific impulse values of 80% of theoretical shifting equilibrium at  $L^*$ 's of 300 in. (Test B-5) and 150 in. (Test B-7). Chamber pressure

oscillations of approximately  $\pm 10\%$  were measured during both tests. These oscillations, though greatly reduced from those of the 4-.062-D injector, were larger than those of the single element injector (1-.109-D) (approximately  $\pm 5\%$ ). A small buildup of combustion slag deposit was observed to partially obscure the injector spray nozzles following Tests B-5 and B-6. Similar combustion slag deposits were observed following all subsequent tests with the 4-.156-D injector. Combustion slag deposits over the injector orifice were not observed following any test with the single element injector. Based upon these observations, it is believed the formation of combustion slag deposits on the injector face is directly related to the level of combustion stability.

(U) The planned nominal conditions of Test B-7 were 1,000 psia chamber pressure with the four element flat face injector and 75 in. L\* chamber. During the bipropellant phase of Test B-7, chamber pressure oscillations of  $\pm 6.0\%$  were measured at a nominal chamber pressure of 940 psia. Immediately following termination of  $\text{ClF}_3$  flow, a combustion instability of  $\pm .400$  psi developed, at a mean chamber pressure of approximately 750 psia.

(U) The combustion slag deposit over the injector orifices following test B-7 did not appear to be more severe than that observed in previous tests B-5 and B-6 conducted at similar conditions with higher L\* chambers. The extent of the combustion slag deposits on the 4-.067-F injector face were very difficult to determine as the slag deposit usually broke up during removal of the injector. Since the degree of injector spray nozzle coating could not be accurately determined, it is unknown whether the instability was the result of a greater injector face coating during Test B-7 (compared to Tests B-6 and B-6) or the result of the 75 inch L\* chamber employed during this test. However, based upon the available data, it appears the combustion instability was at least partially the result of the lower L\* chamber, although further testing would be required to verify this hypothesis.

#### 2.6.2.4 Tests B-8 and B-9

(U) The  $L^*$  survey with the 1-.109-D injector was completed during Tests B-8 and B-9. These tests were conducted at chamber  $L^*$  values of 75 and 150 in. and resulted in delivered specific impulse values of 75.7 and 76.8% of theoretical shifting equilibrium, respectively. These data, together with the data from Test No. 4 (300 in.  $L^*$ ) indicate there is no significant effect on performance of  $L^*$  values ranging from 75 to 300 in.

#### 2.6.2.5 Tests B-10 and B-12

(U) Tests B-10 and B-12 were performed to investigate the effect of chamber pressure on performance of the 1-.109-D injector. These tests were conducted with a 150 in.  $L^*$  chamber. Test B-10 resulted in a delivered specific impulse of 67.0% of theoretical value at a chamber pressure of 355 psia. Random chamber pressure oscillations of up to  $\pm 100$  psi occurred during a portion of this test. These oscillations decreased to  $\pm 5\%$  of chamber pressure just prior to shutdown. Chamber pressure oscillations similar to those observed during a portion of this test have been observed during cases of apparently marginal combustion, as combustion often ceases during this time. It would therefore appear that a chamber pressure of nearly 350 psia may be the lower limit for sustained MONEX A combustion with the single element injector.

(U) During test B-12 a delivered specific impulse of 202 sec, 82.7% of theoretical  $I_{sp}$ , was measured at a chamber pressure of 1222 psia. This was the highest performance measured with MONEX A to date. These data indicate that performance increases significantly with increasing chamber pressure.

#### 2.6.2.6 Tests B-11, B-14, and B-15

(U) The effect of chamber pressure on performance of the 4-.067-F injector was investigated during Tests B-11, B-14, and B-15. Test B-11 was performed to investigate performance at a chamber pressure of 500 psia. During Test B-11 the transition to monopropellant operation

was attempted while operating at a chamber pressure of 590 psia in the bipropellant mode. Combustion ceased immediately following the termination of  $\text{ClF}_3$  flow. This datum indicates that chamber pressures greater than 500 psia are necessary to sustain monopropellant combustion with the 4-.067-F injector. No other attempt was made to operate this injector at chamber pressures below 900 psia.

(U) Tests B-14 and B-15 were aimed at investigating performance of the four element flat face injector at 1500 psia chamber pressure. Test B-14 was invalid. Test B-15 resulted in a delivered specific impulse of 206 sec, 82.1% of theoretical  $I_{sp}$ , at a chamber pressure of 1559 psia. This was the highest performance measured with the 4-.067-F injector.

#### 2.6.2.7 Test B-13

(U) Test B-13 was conducted with the 1-.109-D injector and a turbulence ring installed in the 150 in.  $L^*$  chamber. This turbulence ring had a throat diameter of 1.12 in. (chamber inside diameter was 2.66 in. with a 0.485 in. diameter nozzle throat) located 1.8 in. from the injector. The use of the turbulence ring failed to increase performance significantly, as a delivered specific impulse of 78.7% of theoretical was measured at a chamber pressure 794 psia. However, the combustion stability was markedly affected as random chamber pressure of up to  $\pm 300$  psi occurred during the test. Based upon the adverse effect on combustion stability testing with the turbulence ring was discontinued.

### 2.7 Discussion of Results

#### 2.7.1 Effect of $P_c$ on Performance

(U) The most pronounced factor influencing performance, over the range of conditions tested, was found to be chamber pressure. The effect of chamber pressure on specific impulse is illustrated in Figure 7 for the 150 in.  $L^*$  chamber. Data points for both the single (1-.109-D) and four element injector (4-.067-F) are included. Specific impulse of the 1-.109-D injector increased from 67.0% of theoretical at a chamber pressure of 355 psia (Test B-10) to 82.7% of theoretical

at chamber pressure of 1,222 psia (Test B-12). The delivered specific impulse of the 4-.067-F injector of 80.2% of theoretical at a chamber pressure of 995 psia (Test B-6) appears to be comparable to that which would be expected from the 1-.109-D injector at similar chamber pressures. (See Figure 7.) Based upon the limited data available, it appears that performance of the 4-.067-F injector is below that which could be expected from the 1-.109-D element injector at chamber pressures of 1,000 to 1,500 psia.

(U) A graph of the variation of specific impulse efficiency with chamber pressure for all conditions tested to date is presented in Figure 8. This graph includes tests at chamber  $L^*$  values from 75 to 300 inches. Since no points lie more than 2% from the curve shown, it can be concluded that variations of chamber pressure have the most pronounced effect on performance of any parameter varied.

### 2.7.2 Effect of $L^*$ on Performance

(U) The variation of specific impulse with  $L^*$  is shown in Figure 9 for the 1-.109-D and 4-.067-F injectors. These data indicate that performance of the 1-.109-D injector is not significantly affected by variations in  $L^*$  from 75 to 300 in. The two data points at 150 in.  $L^*$  and 300 in.  $L^*$  shown for the 4-.067-F injector indicate specific impulse is not significantly affected by variations in  $L^*$  over this range. The only test attempted at 75 in.  $L^*$  with the 4-.067-F injector (Test B-7) resulted in unstable combustion. This is indicative of marginal combustion conditions under these conditions. However, further testing would be required to verify this indication.

(U) The higher specific impulse of approximately 4% shown in Figure 9 for the 4-.067-F injector should not be interpreted as a direct performance comparison of the two injectors. The tests with the 4-.067-F injector were conducted at chamber pressures of 955 and 995 psia, while the tests with the 1-.109-D injector were conducted at a chamber pressure of approximately 750 psia. This difference in chamber pressure of approximately 230 psia is believed responsible for the higher performance of the four element injector shown in Figure 9.

### 2.7.3 Combustion Stability

(U) The single element injector configuration (1-.109-D) employed during the Baseline Test Series and Checkout Tests 9, 10, and 11 produced the

smoothest combustion of any injector tested to date. Chamber pressure oscillation of approximately  $\pm 5\%$  were usually measured with this injector. Chamber pressure oscillations of  $\pm 8$  to  $10\%$  were observed during tests with the flat face four element injector (4-.067-F). These greater chamber pressure oscillations of the 4-.067-F injector are attributed, at least in part, to moderate coating of the injector spray nozzles. Severe coating of the injector spray nozzles, such as observed with the 4-.062-D injector (Tests B-1 through B-3), are believed to be responsible for the high (up to  $\pm 400$  psi) chamber pressure oscillations observed with this injector. These combustion deposits are believed to have disturbed the injector spray pattern and resulted in marginal combustion conditions. Combustion ceased during several cases of severe combustion instability. This further substantiates the theory of marginal combustion under these conditions.

(U) Based upon these data, it is concluded that stable monopropellant combustion can be achieved with MONEX A under conditions which produce a finely dispersed propellant spray pattern.

## SECTION III

### SUMMARY AND CONCLUSIONS

(U) The most significant factor affecting performance of MONEX A over the range of conditions evaluated was chamber pressure. Performance increased from 67.0 to 82.7% of theoretical shifting equilibrium with a chamber pressure increase from 355 to 1,222 psia.

(U) Performance of the single element injector (1-.109-D) and the four element flat face injector were found to be comparable at a chamber pressure of 1,000 psia. However, performance of the single element injector at chamber pressures above 1,200 psia was higher than that of the four element flat face injector (4-.067-F).

(U) Variations in  $L^*$  from 75 to 300 inches were found to have no significant effect on performance of the single element injector. Performance of the four element flat face injector was found to be similarly unaffected by a variation in  $L^*$  from 150 to 300 inches. The only test attempted at 75 in.  $L^*$  with this injector (4-.067-F) resulted in unstable combustion, indicating a possible adverse effect of the reduction in  $L^*$  to 75 inches.

(U) Combustion slag deposits were found to severely coat the spray nozzle orifices of the four element dished face (4-.062-D) injector. The degree of injector spray nozzle coating was greatly reduced with the four element flat face (4-.067-F) injector. The severity of these combustion slag deposits was found to adversely affect combustion stability. The 1-.109-D single element injector produced the smoothest combustion (oscillations of  $\pm 5\%$  of chamber pressure) of any injector tested to date. Slag deposits over the injector spray nozzle were not observed following any tests with the single element injector.

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## SECTION IV

## FUTURE WORK

(C) Completion of the baseline test series concluded the planned testing with MONEX A. During the next report period, MONEX DW testing will be initiated. It is planned to conduct a brief series of ignition tests to investigate the ignition characteristics of MONEX DW and CIF<sub>3</sub>. Following these tests, the Series I performance tests will be undertaken to investigate the effect of L\* and chamber pressure on performance. Performance tests with both the single element and four element flat face injector are planned.

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## 13. ABSTRACT

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(C) This report summarizes the work performed during the second quarter of a 12-month program designed to evaluate and characterize the combustion efficiency of MONEX DW, a beryllium-containing monopropellant, in a liquid injection type engine at a nominal 250 lbf thrust level. Initial checkout tests and a series of baseline performance tests have been completed with MONEX A, an aluminum-containing monopropellant. The results of these tests indicate performance of MONEX A increases with increasing chamber pressure. Delivered specific impulse values exceeding 202 lbf-sec/lbm (82% of the theoretical shifting equilibrium value) were measured at chamber pressures greater than 1200 psia.

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